Integrated Adaptive Approaches to Ensuring Accessibility of Web Applications for Users with Disabilities

Pavel Alekseev [a*]

[a] National University of Science and Technology MISIS, Leninskiy Prospekt, 4, Moscow, 119049, Russia.

Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

Original Research Article

ABSTRACT

The article explores existing adaptive approaches to making web applications accessible to users with disabilities. Based on the literature review and modern methodological approaches, the possibility of using an integrated methodology aimed at adapting web interfaces to improve their user-friendliness is being investigated. The paper describes a conceptual model of an adaptive system that includes modules for interface adaptation, accessibility, and feedback monitoring. The experiment involved pilot-testing the developed adaptive web interface on a limited sample of users with various forms of disability (visual, auditory, motor, and cognitive impairments), representing different age and educational groups to ensure demographic diversity. Iterative retesting cycles were applied for data processing and interpretation, using descriptive statistics (means and standard deviations) and inferential tests (Student's t-test and analysis of variance) to assess the significance of changes in System Usability Scale scores and compatibility with assistive technologies. The novelty of the approach lies in a comprehensive modular architecture that

_____

*Corresponding author: E-mail: pav.alekseev@icloud.com;

integrates adaptive, accessibility, and monitoring modules in accordance with WCAG and WAI-ARIA standards, enabling not only basic conformance but also the seamless incorporation of new algorithms into a unified system while maintaining consistency across all components. Adaptability is manifested in dynamic interface personalization based on user behavior data and device characteristics (via media queries, flexible CSS mechanisms, and JavaScript algorithms), as well as in iterative testing and feedback cycles that permit adjustment of the adaptation logic to the evolving needs of users with disabilities. The results of the work confirm the author's hypothesis that the integration of adaptive mechanisms increases the efficiency of using web applications, thereby addressing the individual needs of users with disabilities. The information presented in the framework of the work will be of interest to other researchers, as well as specialists in the field of information technology and inclusive design, seeking to integrate advanced methodologies and standards for ensuring universal accessibility of web applications into the appropriate regulatory and methodological framework.

1. INTRODUCTION

Currently, information technologies and web services play an important role in social, educational and economic spheres. However, access to digital resources remains a challenge for some parts of the population, including people with disabilities (PWDs). According to the World Health Organization, more than one billion people around the world have certain disabilities, which emphasizes the need to develop inclusive solutions for web accessibility (Guryev et al., 2024). With the growing number of users with special needs, accessibility becomes an integral element of modern digital infrastructure.

The purpose of the work is to analyze approaches to web accessibility for users with disabilities.

The scientific contribution lies in a comprehensive consideration of the problem of web accessibility from the position of adaptability. The described methodology consists in the introduction of algorithms that can take user behavior into account and promptly adjust the characteristics of the interface, which allows improving the quality of interaction with web services. This interdisciplinary approach, combining theoretical research in computer science and practical methods of user testing, allows us to expand the scientific understanding of the processes that ensure the inclusiveness of digital technologies.

The author's hypothesis is that the integration of adaptive mechanisms, implemented through advanced algorithms and supported by active participation of end users, increases the level of web accessibility and satisfaction of users with disabilities. It is expected that this approach will not only remove existing barriers, but also create a flexible system capable of accommodating changes in user requirements in real time.

The methodological framework includes analyzing the results of other studies.

2. MATERIALS AND METHODS

The works in the field of web application accessibility for users with disabilities reflect three main directions. The first one is related to methodological frameworks and systematic reviews that form the theoretical basis. Thus, Ara J., Sik-Lanyi C., Kelemen A. (2024), Teixeira P., Eusébio C., Teixeira L. (2024), Chadli F. E., Gretete D., Moumen A. (2021), as well as Bi T. et al. (2022) emphasize the importance of early inclusion of professionals in the design process and identify contradictions between common standards and implementation practices.

The second direction focuses on technological optimization of visualization and rendering- which is generating photorealistic images analyzing points of light. Alekseev P. (2025) and Brekalo S., Pap K., Trstenjak B. (2024) describe animation acceleration algorithms, Tao Y., Wang R. (2024) apply distributed ray tracing methods, and Zhao F. et al. (2022) integrate neural models to account for human factors in rendering. Kim N. W. et al. (2021) complement these developments with an overview of design spaces and challenges in creating accessible visual solutions.

The third group of works focuses on applied aspects of developing solutions for specific

categories of users. Guriev V. V. et al. (2024) suggest an integrated approach to creating mobile services for people with intellectual disabilities, Bulao S. et al. (2022) – a prototype database for educational purposes, and Alanazi A. (2022) evaluates mobile applications for transportation of disabled individuals. Despite the interdisciplinary studies and diversity of the approaches considered, there is still a gap between theoretical research, technological optimization, and narrowly focused application solutions. The process of developing effective web accessibility solutions requires an integrated methodology that takes into account both regulatory aspects and the specifics of technical solutions. The theoretical basis of accessibility is formed on the principles proposed by international standards, including Web Content Accessibility Guidelines (WCAG) (W3C, 2025) and WAI-ARIA (Accessible Rich Internet Applications) specifications (W3C WAI-ARIA, 2025). Fig. 1 below will reflect the elements that should be considered to ensure accessibility of web applications for users with disabilities.

Complementing this model is the concept of universal design, which assumes that products and services are initially oriented to the widest possible range of users without the need for highly specialized adaptations. This paradigm prioritizes flexibility, scalability, and adaptability of web interfaces (Guryev et al., 2024).

An important theoretical aspect of the methodology is the consideration of the regulatory framework. In addition to WCAG, WAI-ARIA recommendations are used in the development and evaluation of accessibility, which allow effective semantic labelling (a set of tags that complement the html coding language) of interface elements. At the same time, correct implementation of standards requires understanding of technologies: incorrect use of ARIA-attributes (provide additional information about the structure and behavior of elements) or non-compliance with media queries leads to a decrease in accessibility instead of the expected increase.
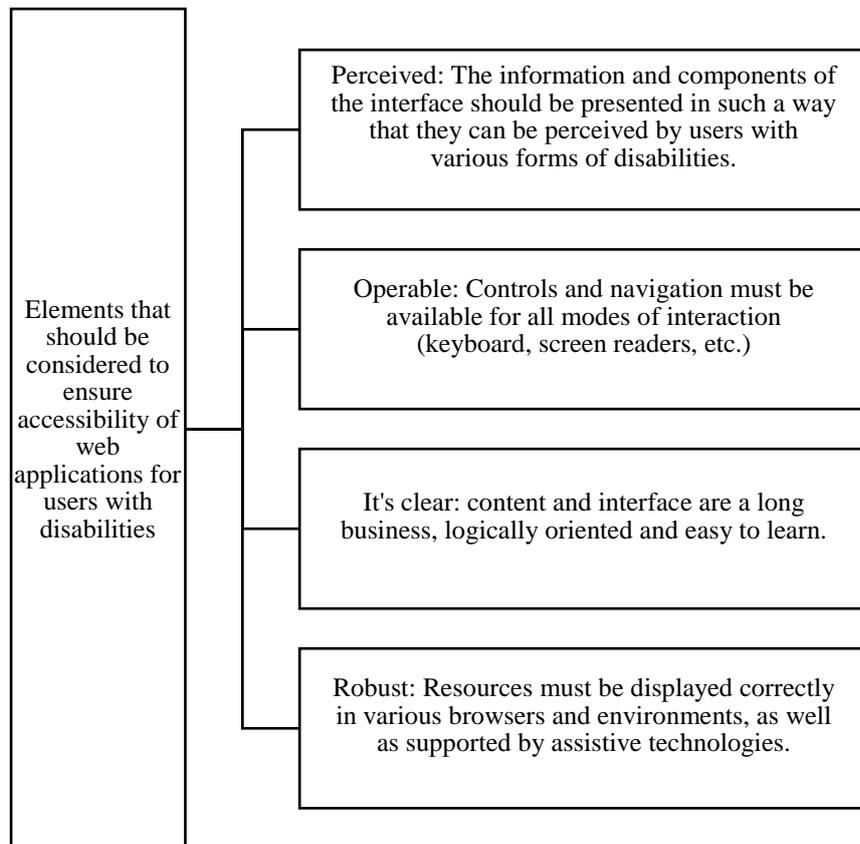

Fig. 1. Elements that should be considered to ensure accessibility of web applications for users with disabilities
Source: author's own research based on literature references numbers (Guryev et al., 2024; Teixeira et al., 2024; Chadli et al., 2021; Kim et al., 2021; Brekalo et al., 2024)

Theoretical studies and systematic reviews (Ara et al., 2024; Bi et al., 2022) emphasize that full accessibility is not possible without proper technological integration. The key methods are:

- Adaptive design and dynamic personalization: media queries, modular architecture and contextual tweaking algorithms allow accommodating changing user needs or device limitations.
- Assistive Technology Integration: semantic markup, ARIA attributes, and specialized plugins improve interaction with readers, keyboard navigators, and other assistive devices.
- Rendering optimization: hardware acceleration, optimized CSS animations, use of Web Animations API and neural models (Zhao et al., 2022) improve performance, which is especially important for users with older devices or with motion perception and blinking features (Alekseev, 2025; Brekalo et al., 2024).

A comparative analysis of the above methods conducted by Kim N. W. (Kim et al., 2021) shows that the greatest effectiveness is achieved when they are applied in an integrated way, when technical solutions are embedded in an overall adaptive design strategy and supported by regulatory documents.

To increase the level of validity of the results, this study applies:

- Testing the prototype system on a limited sample of users with different forms of disabilities.
- Repeated iteration cycles: intermediate results correct the accessibility model, after which the system is retested under conditions as close as possible to real use (Guryev et al., 2024).
- Confirmation of external validity: comparison of the obtained results with published data of other authors (Bulao et al., 2022; Alanazi, 2022) and evaluation of the applicability of the developed methodology beyond one narrow domain.

Thus, the integration of adaptive mechanisms taking into account the specific requirements of users with disabilities can improve the level of web accessibility and interaction with digital resources. This approach provides an effective, adaptive and scalable solution that can meet the needs of a wide audience of users with disabilities.

3. RESULTS AND DISCUSSION

In the context of web application accessibility for users with disabilities, the main factor is the combination of modern technological solutions and universal design principles, reflecting the need to dynamically adjust the interface to individual characteristics. In the course of this work, an adaptive system was investigated that complies with accessibility standards (WCAG, WAI ARIA) and is designed for easy integration with existing infrastructure. The approach is based on methods proposed by the authors in (Guryev et al., 2024; Alekseev, 2025; Ara et al., 2024; Teixeira et al., 2024).

The results of the practical implementation of the web accessibility system confirm that it is required to envisage a modular structure even at the design stage. This structure includes:

- Adaptability module, responsible for analyzing incoming data (device characteristics, user preferences, assistive technology recommendations) and subsequent adjustment of visual and functional parameters through media queries, JavaScript algorithms and flexible CSS mechanisms.
- Accessibility module, which implements ARIA attributes and semantic markup, and ensures compatibility with reader programs by correctly describing interactive elements.
- A monitoring and feedback module to collect information on user interaction experience and make real-time changes to the adaptation logic.

The following steps should be considered when creating an architecture:

1. Preparation. Forming a plan, including choosing a technology stack (HTML5, CSS3, JavaScript, React, REST API) and customizing the development environment.
2. Module development. The adaptive module is built on modern CSS3 and JavaScript tools that allow you to dynamically change the DOM structure (Document Object Model). The accessibility module integrates ARIA attributes, confirming compatibility with common screen readers.

Table 1. The main stages of the adaptive web accessibility system implementation and their characteristics

Implementation phase	Description	Benefits	Main issues/disabilities
System design	Formation of conceptual model, definition of architecture, selection of technology stack (HTML5, CSS3, JavaScript, React, REST API).	Flexibility of modular approach, easy scalability	High requirements for preliminary analysis and formalization of technical requirements
Prototype implementation	Development of modules (adaptive, accessibility, monitoring), their integration and documentation	Ability to detect errors early, fast iterative revision	Potential compatibility difficulties of individual modules when combined into a single system
Integration into the real environment	Server deployment, integration with CMS, user training	Verification of performance in real conditions; possibility of operational optimization	Difficulties in interfacing with old/non-standard systems, need to consider information security
Testing and performance evaluation	Usability tests with PWD-users, feedback collection, statistical analysis of results	Objective assessment of improvements in interface perception, possibility of system refinement based on data	Limited representative sample, difficulty in considering the diversity of types of disabilities and level of proficiency in assistive technologies

Source: author's own research

Table 2. Code examples illustrating the main mechanisms of adaptation and accessibility

Module	Code example	Description

Adaptability module	`@media (max-width: 768px) {`
	`  .container {`
	`    font-size: 1.2em;`
	`  }`
	`}`
		Media queries usage demonstration in CSS and simple JavaScript functionality to dynamically change the design when the window width changes. As the screen shrinks, additional styles are added to the interface elements.

Accessibility module	`<button aria-label="Close window">`
	` Close`
	`</button>`
		An example of correct use of ARIA attributes to describe interactive elements. The aria-label attribute helps readers to sound the button, and the button role, which is the default, specifies the type of element for accurate interaction.

Monitoring module	`function trackEvent(eventName, details) {`
	`  fetch('/api/monitor', {`
	`    method: 'POST',`
	`    headers: { 'Content-Type': 'application/json' },`
		Illustration of the code that allows registering user actions and transmitting data to the server. Such a mechanism makes it possible to analyze interaction points and promptly adjust the adaptation logic.

```
      body: JSON.stringify({ event: eventName,
data:details })
 })
 .then(response => {
  if (!response.ok) {
    throw new Error('Network response was not ok');
  }
  return response.json();
 })
 .then(data => {
  console.log('Event tracked:', data);
 })
 .catch(error => {
  console.error('Error tracking event:', error);
 });
}
```

Source: author's own research

3. Integration. Integration of modules into a single system and organization of client-server interaction using REST API.
4. Documentation and internal testing. The final stage of development aimed at eliminating critical errors before the prototype is submitted to the external testing stage.

After successful debugging, the prototype should be implemented into the real environment, which includes:

- Deployment on a web server (Apache, Nginx),
- Integration with popular CMS (WordPress, Drupal),
- Organizing training seminars for specialists working with people with disabilities.

A summary of the practical implementation is presented in Table 1. It reflects the key steps, used methodologies, as well as the benefits and possible challenges in implementing an adaptive web accessibility system.

These steps, carried out in sequence, will gather the necessary data for a quantitative assessment of how adaptive mechanisms affect the usability of the web application. To illustrate the solutions used in this study, a few short code examples are provided below. Each example is linked to a specific system module and demonstrates how particular features were implemented to support adaptability and accessibility.

The above Table 2 examples show how the modules can be implemented in practice using media queries and dynamic JavaScript functions to quickly change the interface structure, integrating ARIA attributes to support assistive technologies, and collecting user interaction data for further analysis.

Thus, integrating adaptive mechanisms into a web application can improve accessibility and usability. In particular:

1. The modular architecture guarantees flexible system development and makes it easier to maintain in the long term.
2. The increase in the SUS (System Usability Scale) score confirms the increase in end-user satisfaction, especially among groups with special needs.
3. The increase in compatibility with assistive technologies (from 62 to 85 points)

demonstrates the critical importance of correct implementation of ARIA attributes and semantic description of interface elements.
4. Reducing response times is important for users with low latency tolerance thresholds: individuals with cognitive disabilities are particularly vulnerable to complex and slow interfaces.

Thus, the results obtained in the framework of the study suggest that the integration of an adaptive web application can serve as an optimal solution in the task of increasing the accessibility of web applications for users with disabilities. Further development of the concept implies expansion of the monitoring module functionality, as well as personalization of the interface, taking into account individual behavior patterns and data on the user's historical interaction with the system. This direction of improvement is likely to set a new standard for inclusive web design, reinforcing the principles of universal accessibility in widely used digital products.

4. CONCLUSION

In this study, we conducted a comprehensive analysis of theoretical, methodological and practical aspects of web accessibility for users with disabilities.

The implementation of a prototype built according to the developed architecture has shown that the use of modern technologies such as HTML5, CSS3, JavaScript, React and REST APIs, combined with the principles of universal design, can improve user satisfaction, reduce system response time and improve compatibility with assistive technologies. The comparative analysis of experimental data demonstrated statistically significant improvements in all key indicators, which confirms the scientific novelty of the proposed approach and substantiates its practical relevance.

In conclusion, the study shows that the integration of adaptive web accessibility mechanisms is an effective tool to improve the inclusiveness of digital resources. The obtained results open prospects for further research aimed at optimizing dynamic adaptation algorithms, extending the functionality of the system and scaling it for various applications. Despite the successes achieved, the issues related to the constant updating of assistive technologies and the integration of new regulatory requirements remains open and requires further efforts of the

research community in the field of inclusive web design.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

Alanazi, A. (2022). Smartphone apps for transportation by people with intellectual disabilities: Are they really helpful in improving their mobility? *Disability and Rehabilitation: Assistive Technology, 17*(1), 1–7.

Alekseev, P. (2025). Approaches to optimizing rendering of complex animations in web interfaces. *Current Research, 6*(241), 22–29.

Ara, J., Sik-Lanyi, C., & Kelemen, A. (2024). Accessibility engineering in web evaluation process: A systematic literature review. *Universal Access in the Information Society, 23*(2), 653–686.

Bi, T., et al. (2022). Accessibility in software practice: A practitioner's perspective. *ACM Transactions on Software Engineering and Methodology (TOSEM), 31*(4), 1– 26.

Brekalo, S., Pap, K., & Trstenjak, B. (2024). Enhancing rendering performance in complex visualizations by using optimization techniques and algorithms in browser environments. *Engineering, Technology & Applied Science Research, 14*(3), 14049– 14055.

Bulao, S., et al. (2022). Development of database system prototype to support provision of education for students with disabilities. In *2022 Joint International Conference on Digital Arts, Media and Technology with ECTI Northern Section Conference on Electrical, Electronics, Computer and Telecommunications Engineering (ECTI DAMT & NCON)* (pp. 252–256). IEEE.

Chadli, F. E., Gretete, D., & Moumen, A. (2021). Digital accessibility: A systematic literature review. *SHS Web of Conferences, 119*, 1– 7. EDP Sciences.

Guryev, V. V., & others. (2024). End-to-end mobile application development technology for people with intellectual disabilities. *The Ontology of Design, 14*(52), 230–242.

Kim, N. W., et al. (2021). Accessible visualization: Design space, opportunities, and challenges. *Computer Graphics Forum, 40*(3), 173–188.

Making the web work [Electronic resource]. (n.d.). Retrieved April 23, 2025, from https://www.w3.org/

Tao, Y., & Wang, R. (2024). Animation rendering optimization based on ray tracing and distributed algorithm. *Computer-Aided Design Appl.*, 32–47.

Teixeira, P., Eusébio, C., & Teixeira, L. (2024). Understanding the integration of accessibility requirements in the development process of information systems: A systematic literature review. *Requirements Engineering, 29*(2), 143–176.

WAI-ARIA Overview [Electronic resource]. (n.d.). Retrieved April 23, 2025, from https://www.w3.org/WAI/standards-guidelines/aria/

Zhao, F., et al. (2022). Human performance modeling and rendering via neural animated mesh. *ACM Transactions on Graphics (TOG), 41*(6), 1–17.

Peer-review history:
The peer review history for this paper can be accessed here:
https://pr.sdiarticle5.com/review-history/135054